

December 15, 2017

Ms. Sharon DeMeo
U.S. Environmental Protection Agency – Region 1
Office of Ecosystem Protection, Industrial Permits Branch
5 Post Office Square, Suite 100
Boston, MA 02109-3912

Subject: Comments on the draft determination of technology-based effluent limits for flue gas desulfurization and bottom ash wastewater at Public Service of New Hampshire Merrimack Station

Dear Ms. DeMeo:

The Electric Power Research Institute (EPRI) appreciates the opportunity to provide comments to the U.S. Environmental Protection Agency on the draft determination of technology-based effluent limits for flue gas desulfurization (FGD) and bottom ash wastewater at Public Service of New Hampshire Merrimack Station. EPRI focused our analyses on the physical/chemical and vapor compression evaporation (VCE) FGD wastewater treatment and bottom ash discharge ban cost effectiveness assessment.

If you have any questions, please contact me at 650 855 2362 or pchu@epri.com.

Sincerely,



Paul Chu
Senior Program Manager
Environment Sector
EPRI

EPRI Comments on the Revised Draft Determination of Technology-Based Effluent Limits for Flue Gas Desulfurization Wastewater at Merrimack Station in Bow, New Hampshire

PREPARED FOR: U.S. Environmental Protection Agency - Region 1
PREPARED BY: Electric Power Research Institute
DATE: December 15, 2017

Introduction

The Electric Power Research Institute (EPRI) was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together member organizations, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of power generation, delivery, and use, including health, safety, and environment. EPRI has been active in characterizing flue gas desulfurization (FGD) wastewaters and evaluating treatment technologies since 2006. This work includes characterization of FGD wastewaters, evaluation of mercury and selenium chemistry in FGD wastewaters, and the evaluation of physical/chemical, biological, and vapor compression evaporation (VCE) wastewater treatment approaches. (The term VCE in this document is used to describe the thermal treatment consisting of a Brine Concentrator followed by a crystallizer system).

EPRI is providing technical comments to Region 1 of the U.S. Environmental Protection Agency (EPA) on the draft permit for wastewater discharges for the Public Service of New Hampshire (PSNH) Merrimack Station. On February 28, 2012, EPRI provided technical comments to an earlier, proposed permit dated September 30, 2011. These earlier comments focused on the cost-effectiveness evaluation for physical/chemical and biological treatment for FGD wastewater. On August 14, 2014, EPRI provided technical comments to an earlier, proposed permit dated April 18, 2014. These comments focused on the cost-effectiveness evaluation for physical/chemical and evaporative treatment for FGD wastewater.

The Merrimack Station has cyclone coal-fired boiler and air emission control systems including a selective catalytic reduction (SCR) and electrostatic precipitator (ESP), as well as the wet FGD.

FGD Wastewater and Bottom Ash Transport Water Treatment Cost-Effectiveness Evaluation

EPRI reviewed the Statement of Substantial New Questions for Public Comment regarding Merrimack Station (National Pollutant Discharge Elimination System [NPDES] Permit No. NH0001465). The following comments are presented in response to the Statement's request for comment on how the 2015 Steam Electric ELGs should be applied to set the Final Permit's requirements for Merrimack Station's FGD and bottom ash (slag) wastewater. The term 'bottom ash' is used herein although the type of boiler at Merrimack (cyclone coal-fired boiler) produces a bottom ash material more commonly referred to as slag.

EPRI believes it is important to assess the cost effectiveness of wastewater technologies by comparing their estimated pollutant reductions to the costs of the technologies. This is a standard mechanism used by EPA to evaluate proposed effluent limitations guidelines, and it provides a useful metric for

examining whether application of further technologies is warranted. In the case of Merrimack, EPRI's analysis demonstrates that certain technologies are not cost-effective, as described below.

To evaluate the cost effectiveness of FGD wastewater treatment, EPRI used EPA's cost effectiveness methodology and considered three types of treatment: (1) Physical/chemical treatment; (2) incremental vapor compression/evaporation (VCE) and crystallizer to be added on to the physical/chemical treatment; and (3) an incremental addition of a drum dryer. The pollutant removals and costs for FGD treatment are included in Table 1. The supporting calculation details are provided in Appendix A.

Physical/chemical treatment (i.e., clarification and chemical precipitation, followed by an EMARS [Enhanced Mercury and Arsenic Removal System] absorber; termed at Merrimack the Primary Wastewater Treatment System [PWWTS]) is the first level evaluated, using sample results from the site's current operation. Incremental VCE and Crystallizer removal is defined here as the removal of all pollutants in the effluent from the physical/chemical treatment process. This is done because although the crystallizer generates a liquid brine, it is currently managed in a way that avoids discharge to a receiving water body. Because completely eliminating liquid discharge with the VCE and Crystallizer is challenging, an evaluation is also done of the costs and benefits of adding a drum dryer to manage the crystallizer brine as a contingency plan in case the station is not able to get the thermal evaporation system to fully eliminate a liquid brine.

The results of the FGD wastewater cost effectiveness analysis show that, for Merrimack, all technologies beyond physical/chemical treatment are not cost effective. This is not surprising, because physical/chemical treatment at Merrimack removes approximately 90 percent of the total pollutants in the wastewater. The table below compares the Merrimack results using EPA's standard cost-effectiveness metric of costs per toxic weighted pound equivalents (TWPEs) to the highest value cost per TWPE ever established by EPA in any effluent guideline rulemaking (Electrical and Electronic Components, at \$404/TWPE) to EPA's estimated cost effectiveness value for the entire 2015 Steam Electric Effluent Limitations Guidelines (ELG) Rule.

Cost Effectiveness Analysis	Cost Effectiveness Ratio (1981 Dollars per TWPE)
EPRI Merrimack: Physical/Chemical	300 (170 if only O&M costs are considered)
EPRI Merrimack: Incremental VCE and Crystallizer	4,208 (1,889 if only O&M costs are considered)
EPRI Merrimack: Incremental Drum Dryer	588
EPA: Electrical and Electronic Components ¹	404
EPA: 2015 Steam Electric ELG Rule ²	136

Even the cost of physical/chemical treatment alone at Merrimack is well beyond the cost effectiveness ratio EPA derived for the entire 2015 ELG Rule. And the cost effectiveness ratio for incremental VCE and crystallizer technology at Merrimack is more than 10 times the highest value cost effectiveness ratio ever promulgated by EPA.

Based on EPRI's calculations, approximately 90 percent of PSNH Merrimack's total pollutant removal (calculated as toxic weighted pound equivalents [TWPE]) from FGD wastewater treatment is

¹ *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*, USEPA, 2015. Page F-10.

² *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*, USEPA, 2015. Page F-12.

accomplished by the physical/chemical wastewater treatment system. Only 10 percent of the total pollutant removal can be attributed to the VCE system.

EPRI also conducted an evaluation of the cost effectiveness of bottom ash transport water treatment using remote settling of bottom ash and a closed-loop reuse of the ash/slag transport water. The cost effectiveness calculations were performed by estimating the pollutant removals for each technology and comparing these removals with the costs of the technologies.

The pollutant removals and costs for the closed-loop bottom ash transport water system are included in **Table 2**. The supporting calculation details for bottom ash are provided in **Appendix B**.

The cost/TWPE ratio of closed-loop bottom ash handling system is \$2,724 /TWPE (in 1981 dollars). The following table compares this Merrimack site-specific, wastestream specific cost per TWPE to various EPA cost effectiveness values.

Cost Effectiveness Analysis	Cost Effectiveness Ratio (1981 Dollars per TWPE)
EPRI: Merrimack Bottom Ash Closed-Loop System	\$2,797
EPA: Electrical and Electronic Components ³	\$404
EPA: 2015 Steam Electric ELG Rule ⁴	\$136
EPA: 2015 ELG Bottom Ash Closed-Loop, Zero Discharge ⁵	\$314

The Merrimack site-specific cost effectiveness ratio is more than eight times the cost effectiveness ratio EPA estimated for treatment of the bottom ash transport water wastestream in the 2015 rule. These numbers should be comparable, but because of Merrimack's low pollutant loadings and high costs, retrofitting a closed-loop bottom ash transport water system at Merrimack is not at all cost effective.

Challenges of FGD Wastewater Systems

Merrimack has operated their FGD wastewater treatment facility since 2012. The operation consists of a Primary Wastewater Treatment System (PWWTS) comprised of a softening and metals removal process, followed by an EMARS (Enhanced Mercury and Arsenic Removal System) absorber. The downstream Secondary Wastewater Treatment System (SWWTS) is composed of a brine concentrator, a crystallizer system (consisting of two crystallizer bodies in a two-effect arrangement) and an Oberlin belt press filter, which evaporate the PWWTS effluent to a solid waste stream, leaving only a small liquid residual. The latter is used for fly ash wetting before being transported to an off-site landfill for disposal.

There is a total of five or six facilities worldwide that have a FGD evaporative wastewater treatment train consisting of softening/metals removal, a brine concentrator, a crystallizer and an Oberlin belt filter process train. With the exception of the Merrimack system, all others operating with FGD wastewater are located in Italy and burn the low-chloride and low-sulfur coal (< 1% sulfur and ~350 mg/kg chlorine), obtained from the same source in Africa. Merrimack has the distinction of operating the only such FGD

³ *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*, USEPA, 2015. Page F-10.

⁴ *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*, USEPA, 2015. Page F-12.

⁵ *Regulatory Impact Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*, USEPA, 2015. Page F-12.

evaporative system treating wastewater generated from burning higher chloride and sulfur (~2.6% sulfur and ~1,000 mg/kg chlorine), Eastern Appalachian coal.

The composition of FGD scrubber waters varies widely and is, in great part, a function of the coal composition, including the chloride content. Other influencing factors are air pollution controls, site-specific process variables, including makeup water chemistry, the type of limestone reagent and the scrubber vessel metallurgy.

After partial softening and metals removal in the PWWTS, the FGD purge is fed to the SWWTS for volume reduction. As water evaporates in the brine concentrator only calcium sulfate and silica precipitate, leaving the soluble salts to concentrate 5 to 8 times. With additional evaporation in the crystallizer, sodium chloride, sodium sulfate and other moderately soluble salts reach their respective solubility limits and begin to crystallize. As the slurry passes through the Oberlin filter, the crystals, along with a small amount of moisture content associated with the solids, are removed while the filtrate, containing the salts of high solubility like nitrates and some halogens, is returned to the crystallizer. This cycle continues to remove crystallized solids but causes the highly soluble salts to stay in solution and build up in concentration. While the small level of moisture content associated with the filtered solids may result in a sufficient wasting of the various soluble species to keep the crystallizers in Italy in balance, the same is not so for the Merrimack plant.

Unless controlled by purging of a small liquor stream, the increasing salinity of the recirculating slurry will cause the boiling point and thus the operating temperature in the crystallizer to rise in excess of 50°F producing an extremely hostile operating environment of high corrosion and potential interference with the overall crystallization process.

Purging of the crystallizers for nitrate and TDS management is standard procedure for conventional power plants that are fed with tertiary sewage water. These plants either have a separate liquor purge, which typically goes to a waste hauler, or, if using a centrifuge for dewatering, is incorporate into the centrifuge cake, which is much wetter compared to that from an Oberlin filter.

Nitrates in tertiary sewage feed, conventional power plant and FGD wastewaters can vary from relatively low to high levels, ranging from a few to 1,500 mg/l in some FGD wastewater evaporative treatment system feed waters. Given that the overall concentration factors of a brine concentrator plus the crystallizer is 15 to 30 times, nitrate levels in excess of 25,000 mg/l are possible even with crystallizer purging. Without such TDS management, nitrates and other soluble salts will rapidly build up until either purged or driven to reach their very high solubility limits with the aforementioned, detrimental consequences. When present at elevated concentrations in the FGD wastewater evaporative treatment system feed, as is the case at Merrimack, crystallizer purging is, therefore, a necessary operating procedure.

In conclusion, operating experience at Merrimack has shown that a small liquor purge is required to keep their crystallizer chemistry in balance, to manage the critical levels of the highly soluble salts and nitrates, and to keep within the process design envelope. Using this technique, the operational problems encountered during the initial FGD wastewater evaporative treatment system operation have been reduced so that Merrimack has been able to operate this "one-of-a-kind", U.S. FGD wastewater treatment system since 2012.

Bottom Ash Transport Water – Challenges of Closed-Loop Operation

EPRI research at sites that have attempted to operate closed-loop bottom ash handling systems has identified several challenges to implementation and operation. Challenges include balancing the water flows into and out to keep the water balance neutral and maintaining water quality in the closed-loop.

Challenges with closing the water balance to eliminate discharge (i.e., having more flow into a closed-loop bottom ash handling system than flows out) stem from the inclusion of non-transport waters in the closed-loop system, including water from storm events. Several non-transport process waters around the hopper or dewatering system come into contact with ash transport water, forcing these waters to be managed in the closed-loop system. Some of these waters (such as hopper cooling water or hopper seal trough water) can be supplied with recirculated ash transport water, but it may not be feasible for others because of water quality or other reasons. Examples include pump seal water, which may not be able to use the recirculated ash water due to solids content abrading the pump seals. Rain water entering the loop through floor drains and uncovered tanks also increase the flows into the overall water balance.

Some water uses in the recirculated ash loop may require additional equipment or modifications, such as:

- Heat exchangers if the recirculated water temperature is too high for equipment limitations and personnel safety
- Storage tanks to store excess water from boiler tube leaks, large maintenance events, or stormwater

Going to closed loop typically requires capturing any significant transport water loss to building sumps by modifying and rerouting sumps near the boiler or modifying the ash hopper design. Additionally, modifications typically are needed to prevent non-transport wastewaters from mixing with the ash transport water to prevent further adding of water to the closed-loop bottom ash handling system.

As each transport of ash leads to contaminants from the ash partitioning into the water, and clean water evaporates from the closed loop, the water quality in the loop can worsen. This is partially offset by contaminants leaving the loop in water entrained in the ash, but EPRI has noted through research at numerous sites that there are challenges in controlling water quality conditions, such as:

- Small and/or less-dense particles not removed by the remote dewatering system can cause plugging in pipes and nozzles, or accumulating in sumps and tanks, which increases cleaning and maintenance requirements.
- Scaling can be caused by ion concentrations increasing in the loop.
- Acidity and/or corrosion has been observed in some recirculated systems, which in one instance was attributed to pipe corrosion and failure.

The 2015 Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category allowed for purges from a closed-loop bottom ash handling system only to an FGD scrubber. However, such a purge may not be feasible if the purge volume required is higher than the FGD make-up demand (due to excess water or water quality control), especially if a plant has an evaporative FGD treatment technology that requires all distillate to be returned to the scrubber. Additionally, ash transport water could require storage (i.e., multiple surge tanks) during plant outages (i.e., scrubber is offline) if maintenance is required on the ash dewatering equipment. Further, purge water from a closed-loop system could have negative impacts on a FGD scrubber's gypsum crystallization and gypsum marketability. In some cases, additional treatment may be required for the transport water for it to be used in a FGD scrubber.

Table 1. Merrimack Cost Effectiveness for FGD Physical/Chemical and Evaporative Wastewater Treatment

	Removal (TWPE per year)	Capital Cost (Million dollars, in 2012 dollars*)	O&M Cost (Million dollars per year)	Total Annualized Cost		Cost Effectiveness Ratio (Dollars per TWPE)	Cost Effectiveness Ratio if Only O&M Costs (1981 Dollars per TWPE)		
				Capital Cost (Million dollars, in 2012 dollars*)	O&M Cost (Million dollars per year)		Capital Cost (Million dollars, in 1981 dollars)	O&M Cost (Million 1981 dollars per year)	Total Annualized Cost (Million 1981 dollars per year)
Physical/ Chemical	4,122	15	1.8	3.3	790		5.7	0.7	1.2
Incremental VCE and Crystallizer	480	31.2	2.4	5.3	11,060		11.9	0.9	2.0
Incremental Drum Dryer	298	2.4	0.2	0.5	1,553		0.9	0.09	0.2

O&M = operations and maintenance

*- Costs shown in 2012 dollars because that is year system installed.

Table 2. Merrimack Cost Effectiveness for Closed-Loop Bottom Ash Handling System

	Removal (TWPE per year)	Capital Cost (Million dollars in 2017 dollars)	O&M Cost (Million dollars per year)	Total Annualized Cost		Cost Effectiveness Ratio (Dollars per TWPE)	Cost Effectiveness Ratio (1981 Dollars per TWPE)		
				Capital Cost (Million dollars in 2017 dollars)	O&M Cost (Million dollars per year)		Capital Cost (Million 1981 dollars)	O&M Cost (Million 1981 dollars per year)	Total Annualized Cost (Million 1981 dollars per year)
Closed-loop bottom ash	192	14.9	0.2	1.6	8,333		5.0	0.06	0.5

O&M costs estimated by EPRI; all other costs are from PSNH.

References

Eastern Research Group, Inc. (ERG). 2009. *Memorandum: Technology Option Loads Calculation Analysis for Steam Electric Detailed Study*. To: Public Record for the Effluent Guidelines Program Plan 2009/2010. From: TJ Finseth, ERG. EPA-HQ-OW-2008-0517.

Electric Power Research Institute (EPRI). 2013. EPRI Comments on Proposed Effluent Limitations Guidelines Rule. Docket ID EPA-HQ-OW-2009. September 20.

Guidance Document for Management of Bottom Ash Handling Water in Compliance with the 2015 Effluent Limitations Guidelines (ELGs). EPRI, 2016. 3002008345

U.S. Environmental Protection Agency (EPA). 2013. *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*. EPA-821-R-13-002. April 19.

Appendix A

FGD Wastewater Treatment Cost-Effectiveness Analysis

Introduction

This appendix provides details on how EPRI estimated cost-effectiveness for flue gas desulfurization (FGD) wastewater treatment. Physical/chemical and vapor compression evaporation (VCE) FGD wastewater treatment pollutant removals were estimated and the costs associated with each system were compared with their removal rates. Cost estimates are based on information provided by Public Service of New Hampshire (PSNH) Merrimack Station.

Pollutant Removals Calculation Methodology

Pollutant removals were defined as the estimated quantity of contaminants removed from wastewater. The estimated contaminants removed were calculated both as concentrations and toxic-weighted pound equivalents (TWPE). TWPE factors are used by the U.S. Environmental Protection Agency (EPA) to express the relative toxicity of pollutants. Calculations use the concentration of contaminants in the water, wastewater flow, and toxic weighting factors (TWF). Data from PSNH Merrimack sampling were used in the calculations.

Summary of Available Data

EPRI's evaluation used data from two sampling episodes at PSNH Merrimack. The wastewater treatment system influent was based on a 5-day sampling episode that ranged from late December 2011 through early January 2012 and an additional sample in July 2014. The physical/chemical treatment system effluent data were based on six data samples ranging from January 2012 through March 2012 and one sample in July 2014. Two sample points occurring on the same day were averaged first before averaging the remaining four data points. Non-detect data were treated as half of the method detection limit. Analytes that were not included as part of the plant PSNH sampling episodes were estimated with data based on the following documents:

- *Physical/Chemical Influent: Memorandum: Technology Option Loads Calculation Analysis for Steam Electric Detailed Study* (ERG, 2009)
- *Physical/Chemical Influent and Effluent: Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (EPA, 2013)

The influent and effluent data were averaged respectively and multiplied by the average flow rate at Merrimack when plant is operating (44 gallons per minute) and TWF to calculate TWPE per year. The flow per year was based on PSNH's estimate of operating roughly 40 percent of the time. The available data are summarized in **Tables A-1, A-2, and A-3**. **Table A-4** summarizes the averaged influent and effluent values, and estimated pollutant removals by physical/chemical (pollutants in physical/chemical influent minus physical/chemical effluent), by VCE (removal of pollutants in physical/chemical effluent) systems and by the Drum Dryer systems (estimated elimination of crystallizer brine).

The Merrimack sample data used in the analysis represent water quality only as a few snapshots in time. Each stream sampled had a variety of dates and sample events. Because of this, the sample data used does not necessarily represent typical or average plant water quality.

Pollutant Removal Estimates

For clarity, the following terms are used:

- **Physical/Chemical removal:** The estimated amount of pollutants removed via physical/chemical treatment (i.e., physical/chemical influent minus physical/chemical effluent)
- **VCE removal:** The amount removed via VCE treatment (i.e. removal of all remaining pollutants in the physical/chemical treatment system effluent). It is noted that this is a conservatively high estimate of pollutant removal as PSNH is required to operate with a small discharge of wastewater (which is currently managed offsite). If this wastewater discharge was counted the cost-effectiveness would be an even higher \$/TWPE value.
- **Drum dryer removal:** The estimated amount of pollutants removed in the crystallizer brine (i.e. removal of all pollutants contained in the crystallizer brine)

The pollutant removal calculation followed EPA's methodology outlined in the Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (EPA, 2013) pollutant removal calculations. However, since the calculation included plant-specific data, our estimate had three deviations from EPA's methodology as follows:

- Actual sampled plant influent/effluent data were used
- Physical/chemical removal was calculated using the influent to the physical/chemical treatment system
- VCE treatment system benefits were calculated starting with physical/chemical system effluent, and assuming all pollutants are eliminated (i.e. no pollution discharged from VCE)
- Drum dryer treatment system benefits were calculated starting with crystallizer brine, and assuming all pollutants are eliminated (i.e. no pollution discharged from the drum dryer)

A summary of the estimated benefit calculation for PSNH Merrimack is presented in **Table A5**.

Table A-1. Merrimack Station Physical/Chemical Influent Data and Average Concentrations (in milligrams per liter [mg/L])

Analyte	Sample Day 1 12/20/11 – 12/21/11	Sample Day 2 01/03/12 – 01/04/12	Sample Day 3 01/04/12 – 01/05/12	Sample Day 4 01/05/12 – 01/06/12	Sample Day 5 01/06/12 – 01/07/12	Sample 7/23/14	Average
Ammonia						1.9	1.9
Nitrate Nitrite as N						100	100
Chloride	9,100	10,000	10,000	10,000	11,000	14,000	10,683
Sulfate	2,200	3,200	2,800	3,200	3,100	1,200	2,617
Cyanide, Total							0.0117 ^b
Aluminum	65.5	45.2	708	85.8	84.3		198
Antimony	0.0178	0.0128	0.0145	0.0152	0.0152		0.0151
Arsenic	0.224	0.206	0.232	0.221	0.233		0.223
Barium	0.579	0.582	0.657	0.407	0.301		0.505
Beryllium	0.00739	0.00978	0.0122	0.0112	0.0101		0.0101
Boron							208 ^a
Cadmium	0.0159	0.0198	0.0208	0.0206	0.0201		0.019
Calcium							4,850 ^a
Chromium	0.665	0.535	0.718	0.608	0.659		0.637
Chromium (VI)	0.088	0.207	1.35	1.91	0.0442		0.720
Cobalt							0.0875 ^a
Copper	0.279	0.314	0.357	0.338	0.341		0.326
Iron	116	104	137	117	128		120
Lead	1.89	1.65	1.7	1.51	1.56		1.66
Magnesium	870	970	948	1010	968		953
Manganese	22.3	25.5	25.9	22.1	23.3		23.8
Mercury	0.183	0.288	0.303	0.239	0.277		0.258
Molybdenum							0.124 ^a
Nickel	1.03	1.08	1.16	1.03	0.992		1.06
Selenium	2.93	2.71	2.86	2.52	2.68		2.74
Silver	0.000781	0.00015	0.00015	0.00015	0.00015		0.000276
Sodium							612 ^a
Thallium	0.02	0.0128	0.014	0.0155	0.0178		0.016
Tin							0.0115 ^a
Titanium							0.608 ^a
Vanadium							0.344 ^a
Zinc	5.1	3.75	4.56	4.11	3.91		4.29

^a Data gap filled with Memorandum: Technology Option Loads Calculation Analysis for Steam Electric Detailed Study (ERG, 2009)

^b There was no available data for cyanide in FGD influent. There is available data for cyanide in the physical/chemical treatment system effluent (Table A-2). Cyanide is not typically removed by physical/chemical treatment, therefore, the value for influent is set equal to the data available for physical/chemical treatment system effluent. Cyanide was analyzed in the 2014 sample, but was not detected. The detection limit is higher than the quantified values in 2012; therefore, the 2014 result is not included in these calculations.

Table A-2. Merrimack Station Physical/Chemical Effluent (VCE Influent) Data and Average Concentrations in mg/L

Analyte	Sample 1/5/12	Sample 1/5/12	Average of 1/5/12 samples	Sample 1/26/12	Sample 2/2/12	Sample 2/9/12	Sample 3/2/12	Sample 7/23/14	Average
Ammonia	0.92		0.92	1.2	1.1			2.7	1.48
Nitrate Nitrite as N	100		100	68	65			100	83.3
Chloride	11,000		11,000	9,500	9,300			13,000	10,700
Sulfate	1,200		1,200		1,200			1,400	1,267
Cyanide, Total	0.02		0.02	0.01	0.005				0.0117
Aluminum	0.0411	0.04	0.0406	0.04	0.218	0.1			0.100
Antimony	5.20E-04	4.08E-04	4.64E-04	7.58E-04	1.55E-03				9.24E-04
Arsenic	0.00498	0.00851	0.00675	0.00956	0.0121	0.00375	0.00812		0.00806
Barium	0.3	0.24	0.27	0.208	0.243				0.240
Beryllium	5.22E-04	6.00E-04	0.000561	0.0006	0.0015				8.87E-04
Boron	980	493	737			357			547
Cadmium	2.07E-04	2.00E-04	2.04E-04	5.87E-04	5.00E-04	5.00E-04	2.00E-04		3.98E-04
Calcium	5050	5010	5030						5030
Chromium	2.50E-04	0.001	6.25E-04	0.001	0.0025	0.0025	0.001		0.00153
Chromium (VI)									0.00209 ^a
Cobalt						0.0025			0.0025
Copper	2.50E-04	0.001	6.25E-04	0.00261	0.00553	0.0025	0.001		0.00245
Iron	0.025	0.1	0.0625	0.1	0.25		0.1		0.128
Lead	1.00E-04	4.00E-04	2.50E-04	4.00E-04	0.001	0.001	4.00E-04		6.10E-04
Magnesium									769 ^a
Manganese	0.293	0.28	0.287	0.349	0.631	1.73			0.749
Mercury	1.05E-05	1.05E-05	1.05E-05	1.22E-05	3.60E-05	2.09E-05	1.72E-05		1.94E-05
Molybdenum	0.14	0.134	0.137	0.373	0.195	0.11	0.419		0.247
Nickel	0.00803	0.00979	0.00891	0.00776	0.0025	0.0126	0.0291		0.0122
Selenium	0.074	0.0689	0.0715	0.104	0.121	0.0822	0.109		0.0975
Silver	5.00E-05	2.00E-04	1.25E-04	2.00E-04	5.00E-04	5.00E-04	2.00E-04		3.05E-04
Sodium	277	259	268						268
Thallium	0.00664	0.00556	0.0061	0.00565	0.00685				0.00620
Tin									0.1 ^b
Titanium									0.01 ^b
Vanadium						0.0025			0.0025
Zinc	5.00E-04	0.002	0.00125	0.002	0.005	0.005	0.002		0.00305

^a Data gap filled with the average value of an earlier data set for the primary wastewater treatment system effluent data during plant startup (late-January 2011).

^b Data gap filled with *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (EPA, 2013)

Table A-3. Merrimack Station Crystallizer Brine Data with Estimated Concentrations in mg/L

Analyte	CRX Liquor (Crystallizer Brine) Estimate ^a
Ammonia	0
Nitrate Nitrite as N	3,400
Chloride	260,000
Sulfate	500
Cyanide, Total	0.06
Aluminum	2
Antimony	0.03
Arsenic	0.4
Barium	3
Boron	1,000
Cadmium	0.05
Calcium	66,000
Chromium	0.3
Chromium (VI)	0.07
Cobalt	0.08
Copper	0.3
Iron	20
Lead	0.08
Magnesium	24,000
Manganese	1.0
Mercury	0.00004
Molybdenum	0.52
Nickel	3
Selenium	1.2
Silver	0.1
Sodium	2,800
Thallium	0.2
Tin	3
Titanium	0.3
Vanadium	0.08
Zinc	0.1

^a Data gap filled with Physical/Chemical Effluent data average (Table A-2), and then cycled up by a factor of 34-fold to reflect the brine concentration taking place in the evaporator and crystallizer.

Table A-4. Merrimack Station Influent and Effluent Average Concentrations and Removals in mg/L * TWF

Analyte	TWF	FGD Wastewater (Phys/Chem Influent)	Phys/Chem Effluent (VCE Influent)	Phys/Chem Removal	VCE Removal	Dryer Removal
Ammonia	0.00111	0.00211	0.00164	0.00046	0.00164	0
Nitrate Nitrite as N	0.0032	0.320	0.266	0.0536	0.266	10.9
Chloride	2.43E-05	0.260	0.260	-	0.260	6.32
Sulfate	5.60E-06	0.0147	0.00709	0.00756	0.00709	0.0028
Cyanide, Total	1.12	0.0130	0.0130	-	0.0130	0.0670
Aluminum	0.0647	13	0.00645	12.8	0.00645	0.129
Antimony	0.0123	0.000185	1.13E-05	1.74E-04	1.13E-05	0.000343
Arsenic	3.47	0.774	0.0279	0.746	0.0279	1.39
Barium	0.00199	0.00101	0.000478	5.27E-04	0.000478	0.00498
Beryllium	1.06	0.0107	0.000937	0.00977	0.000937	0
Boron	0.00834	1.74	4.56	-	4.56	8.34
Cadmium	22.8	0.442	0.00906	0.433	0.00906	1.14
Calcium	0.000028	0.136	0.141	-	0.141	1.85
Chromium	0.0757	0.0482	0.000115	0.0481	0.000115	0.0189
Chromium (VI)	0.517	0.372	0.00108	0.371	0.00108	0.0367
Cobalt	0.114	0.0100	0.000286	0.00971	0.000286	0.00971
Copper	0.623	0.203	0.00153	0.202	0.00153	0.156
Iron	0.0056	0.674	0.000718	0.674	0.000718	0.112
Lead	2.24	3.72	0.00137	3.72	0.00137	0.179
Magnesium	0.000866	0.825	0.666	0.159	0.666	20.6
Manganese	0.102667	2.45	0.0769	2.37	0.0769	0.107
Mercury	110	28.4	0.00213	28.4	0.00213	0.00440
Molybdenum	0.201	0.0250	0.0497	-	0.0497	0.105
Nickel	0.109	0.115	0.00133	0.114	0.00133	0.379
Selenium	1.12	3.07	0.109	2.96	0.109	1.35
Silver	16.5	0.00455	0.00502	-	0.00502	1.65
Sodium	5.49E-06	0.00336	0.00147	0.00189	0.00147	0.0152
Thallium	2.85	0.0457	0.0177	0.0280	0.0177	0.602
Tin	0.301	0.00346	0.0301	-	0.0301	1.02
Titanium	0.0293	0.0178	0.000293	0.175	0.000293	0.00997
Vanadium	0.28	0.0963	7.00E-04	0.0956	7.00E-04	0.0238
Zinc	0.0469	0.201	0.000143	0.201	0.000143	0.00486
Total		56.8	6.3	53.4	6.3	56.5

"-" =Indicates where effluent were greater than influent values. These data were discarded.

Table A-5. Merrimack Station Treatment System Benefits

	Flow (gpy)	Removal Factor (mg/L * TWF)	Removal (TWPE per year)
Physical/Chemical	9,250,560	53.4	4,122
VCE	9,250,560	6.28	480
Drum Dryer	630,720	56.5	298

gpy = gallons per year

Cost Estimate

Cost data were obtained from PSNH Merrimack. Costs were annualized based on a 20-year plant life span at a 7 percent interest rate. Table A-6 summarizes the annualized cost in current dollars and 1981 dollars. Capital and operating costs are provided by PSNH Merrimack for the physical/chemical treatment system and VCE and Crystallizer, they are based on actual costs for their installation at Merrimack. Capital and operating costs for the drum dryer system were estimated based on quotes from an equipment vendor, plus additional costs for the balance of plant.

This system cost reflects its construction as a component of the FGD Scrubber/Clean Air Project. The VCE costs likely would increase if built as a standalone system.

Table A-6. Merrimack Station Cost for Physical/Chemical and VCE Treatment Technologies

	Capital Cost [million dollars]	O&M Cost [million dollars per year]	Total Annualized [million dollars per year]	Capital Cost [1981 million dollars]	O&M Cost [1981 million dollars per year]	Total Annualized [1981 million dollars per year]
Physical/ Chemical ¹	15	1.8	3.3	5.7	0.7	1.2
VCE and Crystallizer ¹	31.2	2.4	5.3	11.9	0.9	2.0
Drum Dryer ²	2.7	0.3	0.5	0.9	0.09	0.2

Notes:

1. Capital and operating costs are actual costs are provided by PSNH Merrimack for the physical/chemical treatment system and VCE and Crystallizer.
2. Capital and operating costs estimated by WSSI, in 2017 dollars (so is pro-rated to 2012 dollars in Table 1 of this memo).

Appendix B

Bottom Ash Sluice Water Treatment Cost-Effectiveness Analysis

Introduction

This appendix provides details on how EPRI estimated cost-effectiveness for a closed-loop bottom ash handling system. Cost estimates are based on information provided by PSNH Merrimack Station.

Pollutant Removals Calculation Methodology

Pollutant removals for bottom ash transport water were defined as the pollutants in bottom ash transport water minus the pollutants in the source water. The estimated contaminants removed were calculated both as concentrations and toxic-weighted pound equivalents (TWPE). TWPE factors are used by the U.S. Environmental Protection Agency (EPA) to express the relative toxicity of pollutants. Calculations use the concentration of contaminants in the water, wastewater flow, and toxic weighting factors (TWF). Data from PSNH Merrimack sampling were used in the calculations.

Summary of Available Data

EPRI's evaluation used data from two sampling episodes at PSNH Merrimack. The bottom ash transport water data were based on one sample taken in July 2013 and an additional sample taken in July 2017. These two data sets were averaged before subtracting out the source water pollutants. The source water data were based on a sample taken in July 2013 corresponding to the bottom ash sample. Analytes that were not included as part of the plant PSNH sampling episodes were estimated with data for source water and bottom ash water based on the following document:

- EPRI Comments on Proposed Effluent Limitations Guidelines Rule (EPRI, 2013)

The source water data was subtracted from the bottom ash transport water and multiplied by the average flow rate on days the plant is operating at Merrimack Station (4 million gallons per day) and TWF to calculate TWPE per year. The flow per year was based on PSNH's estimate of operating roughly 40 percent of the time. The available data are summarized in **Table B-1** and **Table B-2** summarizes bottom ash transport water minus the source water.

The pollutant removal calculation followed the methodology outlined in the *EPRI Comments on Proposed Effluent Guidelines Rule* (EPRI, 2013) pollutant removal calculations.

A summary of the estimated benefit calculation for PSNH Merrimack Station is presented in **Table B-3**.

Table B-1. Merrimack Station Source Water and Bottom Ash Transport Water Concentrations

Analyte	Source Water 07/22/2013 (mg/L)	Bottom Ash Transport Water 07/22/2013 (mg/L)	Bottom Ash Transport Water 07/19/2017 (mg/L)	Bottom Ash Transport Water Average (mg/L)
Aluminum	0.08	0.23	0.67	0.45
Antimony	0.0005	0.0005	0.0005	0.0005
Arsenic	0.0005	0.0005	0.002	0.00125
Barium	0.008	0.009	0.015	0.012
Beryllium	0.0005	0.0005	0.0005	0.0005
Boron	0.025	0.025	0.025	0.025
Cadmium	0.0005	0.0005	0.0005	0.0005
Calcium	4.2	4.6	4.4	4.5
Chromium	0.0005	0.0005	0.002	0.00125
Cobalt	0.0005	0.0005	0.0005	0.0005
Copper	0.03	0.001	0.005	0.003
Iron	0.42	0.66	1.1	0.88
Lead	0.004	0.0005	0.002	0.00125
Magnesium	0.68	0.73	0.75	0.74
Manganese	0.031	0.03	0.047	0.0385
Mercury	0.000002	3.3E-06	0.00005	2.67E-05
Molybdenum	0.0005	0.0005	0.001	0.00075
Nickel	0.0005	0.0005	0.002	0.00125
Selenium	0.0005	0.0005	0.0005	0.0005
Silver	0.0005	0.0005	0.0005	0.0005
Sodium	9	10	12	11
Thallium	0.0005	0.0005	0.0005	0.0005
Tin	0.005	0.005	0.0025	0.00375
Titanium	0.0025	0.01	0.032	0.021
Vanadium				
Zinc	0.013	0.0025	0.01	0.00625
Chloride				
Sulfate	4	9	8	8.5
Nitrate/Nitrite			0.25	0.25
Ammonia-N				
Fluoride				
Cyanide				
Hexavalent Chromium				

Table B-2. Merrimack Station Bottom Ash Transport Water Minus Source Water

Analyte	TWF	Bottom Ash Water Minus Source Water	
		mg/L	mg/L * TWF
Aluminum	0.0647	0.370	0.0239
Antimony	0.0123	-	-
Arsenic	3.47	0.000750	0.00260
Barium	0.00199	0.00400	7.96E-06
Beryllium	1.057	-	-
Boron	0.00834	-	-
Cadmium	22.8	-	-
Calcium	0.000028	0.300	8.40E-06
Chromium	0.0757	0.000750	5.68E-05
Cobalt	0.1143	-	-
Copper	0.623	-	-
Iron	0.0056	0.460	0.00258
Lead	2.24	-	-
Magnesium	0.000866	0.0600	5.19E-05
Manganese	0.103	0.00750	0.000770
Mercury	110	2.47E-05	0.00271
Molybdenum	0.201	0.000250	5.04E-05
Nickel	0.109	0.000750	8.17E-05
Selenium	1.12	-	-
Silver	16.5	-	-
Sodium	5.49E-06	2	1.1E-05
Thallium	2.85	-	-
Tin	0.301	-	-
Titanium	0.0293	0.0185	0.000542
Vanadium	0.28	0.0199 ^a	0.005569
Zinc	0.0469	-	-
Chloride	2.43E-05	1.81 ^a	4.39E-05
Sulfate	5.6E-06	4.5	2.52E-05
Nitrate/Nitrite	0.0032	6.25E-03 ^a	2.00E-05
Ammonia-N	0.00111	0.00 ^a	-
Fluoride	0.035	0.01018 ^a	0.000356
Cyanide	1.12	NA ^a	0
Hexavalent Chromium	0.517	NA ^a	0
Total			0.0394

^a Gap filled with *EPRI Comments on Proposed Effluent Limitations Guidelines Rule*

- Represents no removal, as source water was equal to or greater than bottom ash water data.

Table B-3. Merrimack Station Bottom Ash Treatment System Benefits

	Flow (gpy)	Removal (mg/L * TWF)	Removal (TWPE per year)
Bottom Ash Transport Water Minus Source Water	584,000,000	0.0394	192

TWPE = Toxic Weight Pound Equivalent

Cost Estimate

Capital costs and operating costs were estimated by CH2M. CH2M's estimate was developed using equipment cost quotes, and then adding parametric factors such as piping, contractor profit and engineering. The equipment is primarily the remote submerged flight conveyor (SFC). PSNH has designed a system with one remote SFC. Therefore, the cost is lower than it would be for sites that choose to include redundant systems for reliability. Costs were annualized based on a 20-year plant life span at a 7 percent interest rate. **Table B-4** summarizes the annualized cost in current dollars and 1981 dollars.

Table B-4. Merrimack Station Cost for Closed-Loop Bottom Ash Handling System

	Capital Cost, [million dollars]	Operation & Maintenance, [million dollars per year]	Total Annualized, [million dollars per year]	Capital Cost, [1981 million dollars]	Operation & Maintenance, [1981 million dollars per year]	Total Annualized, [1981 million dollars per year]
Bottom Ash Sluice	14.9	0.2	1.6	5.0	0.06	0.5

Note: Capital costs and operating costs estimated assuming one remote submerged flight conveyor needed.